Using Multi-Criteria Decision Analysis in Natural Resource Management

Gamini Herath
and Tony Prato

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Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2006 by Ashgate Publishing

Published 2016 by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN
711 Third Avenue, New York, NY 10017, USA

Routledge is an imprint of the Taylor & Francis Group, an informa business

British Library Cataloguing in Publication Data
Using multi-criteria decision analysis in natural resource
management. - (Ashgate studies in environmental and natural
resource economics)
1. Natural resources - Management 2. Multiple criteria
decision making
I. Herath, Gamini II. Prato, Tony
333.7

Library of Congress Cataloging-in-Publication Data
Using multi-criteria decision analysis in natural resource management / edited by Gamini Herath and Tony Prato.
p. cm. -- (Ashgate studies in environmental and natural resource economics)
Includes bibliographical references and index.
ISBN 0-7546-4596-7
1. Natural resources--Decision making. 2. Natural resources--Management. I. Herath, Gamini. II. Prato, Tony. III. Series.

HC85. U85 2006
333.701'156--dc22

2006003907

ISBN 9780754645962 (hbk)

Transferred to Digital Printing in 2014

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Preface and Acknowledgements

In the last few decades, we have witnessed significant advancements in our understanding of the relationships between economic development and environmental protection. There is now consensus that a myriad of environmental problems result from unbridled exploitation of the natural environment, and general recognition of the need to address environmental issues in growth and development policy decisions. Many countries are revising their development policies with due recognition of the importance of sustainable use of the environment. The applications of multi-criteria decision analysis (MCDA) to the development and evaluation of natural resource use policies provides a basis for prioritizing policies which if implemented have a greater chance of success in contributing to sustainable development.

Past policies were more oriented toward government priorities even though all stakeholders have legitimate interests in the policy process and mechanisms used for their implementation. Major stakeholders in the policy process are government officials, non-governmental organizations, farmers and foresters, private sector mining companies, watershed managers, and park managers and users. The general public also have specific interests. In developing countries, donor agencies such as the World Bank, The Asian Development Bank and the International Fund for Agricultural Development (IFAD) have policy interests. Selected policies should strike a balance among competing uses and multiple stakeholders. Explicit incorporation of MCDA in policy development has grown slowly and is now recognized as an integral element in environmental decision making.

The inspiration for writing this book came when the first co-editor spent a six-month sabbatical in 2004 at the University of Missouri-Columbia working with the second co-editor. The editors quickly realized that unprecedented degradation of natural resources around the world and the inability of traditional policy analysis to minimize resource degradation warranted the explication of quantitative techniques that provide decision support. MCDA is a useful technique for this purpose. The task of searching for authors, especially from developing countries, was challenging mainly due to lack of empirical application of MCDA techniques in developing countries.

We wish to acknowledge the many people, too many to name, we have worked with over the years, and who have stimulated our understanding and interest in applying MCDA to natural resource management problems. We express appreciation to the contributors for their prompt responses to our innumerable inquiries and editorial comments.

Our sincere thanks go to Nirmitha, Athula and Pavith for their help in clarifying problems encountered in formatting large figures and tables. Last but not least, our heartfelt appreciation goes to Hemamala Herath for her painstaking work in typing, correcting, formatting and assisting in the preparation of the book. She spent hundreds of hours on the computer preparing the book manuscript for publication and facilitating what has been a very challenging journey.

Chapter 1

Role of Multi-Criteria Decision Making in Natural Resource Management

Gamini Herath and Tony Prato

Introduction

Management of natural resources has become a contentious and divisive issue throughout the world. The natural environment is the basis of all economic activity and provides humans with food and water, raw materials needed for the production of consumer goods and services, and ecosystem goods and services. Ecosystem goods include products, such as timber, biomass fuels (coal, crude oil, and natural gas), and natural fiber (cotton and wool) that are used to produce intermediate goods, such as lumber, aluminum, and inorganic fertilizers, and/or consumer goods and services, such as homes, automobiles, clothing, and health care. Ecosystem services include air and water purification, mitigation of floods and drought, detoxification and decomposition of wastes, generation and renewal of soil, biodiversity, partial stabilization of climate, nutrient cycling and pollination, and others (Daily 1997).

National economies and human life depend on the capacity of ecosystems to provide goods and services. In a quarter of the world's nations, crops, timber, and fish still contribute more to the economy than industrial production. Harvesting the bounty of nature provides income and employment opportunities. However, unprecedented increases in population and economic growth during the last few decades have diminished the capacity of ecosystems to provide these benefits. The world's population has reached 6.5 billion in 2005. At plausible rates of growth in population and income per capita, world GDP in 2050 could be four times what it is today (Kirk and Ian 2004). Population and economic growth have contributed to deforestation, soil erosion, landscape fragmentation, water shortages, fish kills, landslides, and loss of biodiversity, and reduced the capacity of natural systems to provide ecosystem goods and services. Unless appropriate action is taken, continued population and economic growth will further damage ecosystems with serious consequences for sustaining long term economic development and human well being.

Resource use problems and degradation of natural resources

Many agricultural and natural resource use decisions involve multiple objectives even among peasant farmers in developing countries. Rapid historical increases in agricultural productivity are not expected to continue in the future due to reduced availability of land and water resources, and land degradation, which can adversely affect human welfare. Management of water resources has become very important due to increasing scarcity and rising demand. Availability and development of water resources need to be evaluated in terms of household, irrigation, and recreational needs, cost, global climate change, and water pollution. In general, natural resource development, use, and management decisions involve multiple conflicting objectives and criteria, and incommensurable units for measuring goods and services.

The management of wetlands needs to be changed in order to improve their quality and ensure that economic development does not degrade their health. Wetlands perform a variety of critical functions in maintaining healthy river systems, and have ecological, hydrologic, and economic value (Herath 2004). They improve water quality, replenish groundwater, retain floodwater, provide habitat for a diversity of plants and animals, trap sediment, reduce nutrients, and remove contaminants. Such critical ecosystem services of wetlands are lost when wetlands are converted to other uses and/or degraded. Stakeholder perceptions of river ecosystems and wetlands need to be changed through education and intervention strategies.

Forest management has become critical because of a multitude of competing uses and functions of forests, including timber harvesting, recreation, water supply, flood control, preservation of air, soil, and water quality, biodiversity conservation, and groundwater retention (Ananda and Herath 2003). The multiple and competing uses of forests have increased the frequency and intensity of forest management conflicts. For example, there have been major conflicts between timber harvesting and conservation of biodiversity in old-growth forests in the Pacific Northwest region of the U.S. and tropical rain forests in the Amazon River Basin. Forest policy making involves considering ecological, socioeconomic, and political processes and values, and making difficult tradeoffs among multiple objectives held by different stakeholders (Gregory and Keeney 1994).

Rapid socioeconomic improvements driven by increased income and wealth have increased the demand for ecosystem services, such as aesthetic enjoyment and recreation. Nature-based tourism is an important income source in many countries and having a pristine environment is paramount for its success. Planning and management of natural areas are inherently difficult because of the multiple attributes of nature-based tourism, and conflicts between use and preservation of those areas. Management of nature-based tourism and natural areas should control use patterns and implement resource protection practices that maintain the quality of visitor experiences without denigrating ecological, cultural, and social values (Figgis 1993, Prato and Fagre 2005).

Globalization and liberalization of markets and intensifying competition in commodity markets have increased uncertainty and instability in natural resource management. With globalization of markets, ecosystems and associated natural resources have become more susceptible to global economic forces and the actions of governmental and donor agencies, such as the World Bank, making it more difficult to manage natural resource systems on a sustainable basis.

The emergence of the concept of sustainable development in the 1980s was a reflection of the failure to safeguard ecosystem values from population and economic growth. Sustainable resource management requires maintaining environmental quality and ecological integrity for future generations.

Community participation

Public concern for the maintenance of nature stems from a deep-rooted concern about our relationship with nature. Greater attention should be given to stakeholder participation in decision making. Public participation is seen as a critical component to legitimize bureaucratic decisions, improve and expand the information base for making decisions, and enhance accountability by opening up decision making to public scrutiny. There is a great deal of interest among policy makers regarding community involvement in collaborative efforts to manage natural resources. Involvement of stakeholder groups in the planning, management, and policy analysis helps to resolve conflicts, increase public commitment and reduce distrust between governmental agencies and stakeholders (Tanz and Howard 1991).

Allowing stakeholder to participate in decision making improves public understanding of the complexities of policy making processes, increases the capacity of governments to respond to public needs and demands, conveys the saliency of public issues, and shapes the formulation of policy alternatives that are more acceptable to the community. Public participation helps to identify and explicitly incorporate the different attributes of decision outcomes and provides a stronger basis for public policy and natural resource management decisions.

Community involvement in decision making has been inadequate and public consultation has been ineffective. Management and policy proposals are often presented to the public after key decisions have already been made. When excluded from the formulation stage, stakeholders have little role in identifying issues, and developing and prioritizing alternative management options. Public participation at this late stage may be little more than a ratification of decisions that have already been made. Communication is critical when involving stakeholders in collaborative decision making and establishing productive linkages between decision makers and the public. Participatory approaches should focus on people and their needs, and engage them in developing a common orientation and shared future vision for ecosystem management. Cooperative efforts can lead to shared agreements and desired community outcomes. Pubic input gathered through traditional consultation approaches is difficult to manage and use. Developing better approaches to public participation allows different perspectives on diverse issues to be represented and discussed and conflicts reconciled. In general, there is a dearth of applications of tested methods for incorporating stakeholder views into decision making.

Values and multiple attributes

Improving decision making for human and natural resource management requires consideration of a multitude of non-economic objectives, such as biodiversity, ecological integrity, and recreation potential. When ecosystems become degraded, the provision of ecosystem services is impaired. There are limits to the changes that ecosystems can undergo and still remain productive. Decision making related to the sustainable use of natural resources involves important tradeoffs because increasing one benefit typically decreases other benefits. For example, converting a natural forest to a plantation forest increases timber output, but reduces wildlife habitat in the remaining forest compared to the pristine forest. Furthermore, the values of environmental attributes, such as biodiversity, cannot be properly measured using monetary criteria; appropriate non-monetary criteria need to be developed.

Methods that facilitate better management and policy decisions must account for the variation in stakeholders' preferences for attributes, and conflicting stakeholder interests and values. As the complexity of decisions increases, it becomes more difficult for decision makers to identify a management alternative that maximizes all decision criteria. This difficulty has increased the demand for more sophisticated analytical methods that consider the myriad of attributes of decision outcomes and differences in stakeholders' preferences for those attributes. The neoclassical economic approach based on maximization of a single objective (i.e., utility for consumers and profit for businesses) has limited applicability in multi-attribute decision problems in natural resource management (Joubert et al. 1997).

Over the past two decades, considerable attention has been focused on developing and using multi-criteria decision making (MCDA) techniques to identify optimal alternatives for managing natural resources. Empirical MCDA techniques continue to be fine tuned and their application to natural resource management problems expanded. As applications expand, new insights are gained about how to improve MADM approaches. However, research is still needed on how best to approach various decision problems.

Potential of MCDA methods

The foregoing discussion highlights the difficulties of natural resource planning and management when there are a multitude of heterogeneous stakeholders, objectives, goals, and expectations, and stakeholder conflicts. Planning requires a multi-objective approach that leads to well conceived and acceptable management alternatives and expands the ability to make decisions in complex natural resource management settings. It also requires analytical methods that examine tradeoffs, consider multiple political, economic, environmental, and social dimensions, reduce conflicts, and incorporate these realities in an optimizing framework.

MCDA techniques have emerged as a major approach for solving natural resource management problems and integrating the environmental, social, and economic values and preferences of stakeholders while overcoming the difficulties in monetizing intrinsically non-monetary attributes. Quantifying the value of ecosystem services in a non-monetary manner is a key element in MCDA (Martinez-Alier et al. 1999, Carbone et al. 2000, Munda 2000). The MCDA process typically defines objectives, chooses the criteria to measure the objectives, specifies alternatives, transforms the criterion scales into commensurable units, assigns weights to the criteria that reflect their relative importance, selects and applies a mathematical algorithm for ranking alternatives, and chooses an alternative (Howard 1991, Keeney 1992, Hajkowicz and Prato 1998). Many authors have described and reviewed MCDA techniques (e.g., Herath 1982, Smith and Theberge 1987, Stewart 1992, Hayashi 2000). Hence, an exhaustive review of MCDA methods is not provided here.

MCDA techniques encompass a wide variety of methods which belong to different axiomatic groups and schools of thought. Keeney (1982) defines MCDA as a formalization of a common sense approach to decision problems that is appropriate when decision problems are too complex to be solved by informal use of common sense. Several distinct schools of thought appear in the MCDA literature. Value and utility based approaches assume that there is a value function or utility function. Multiple attribute value theory (MAVT), multiple attribute utility theory (MAUT), and the simple multi-attribute rating technique (SMART) are the most common approaches within this school. MAVT belongs to the quantitative riskless category and MAUT and ELECTRE belong to the quantitative risk category. The Analytic Hierarchy Process (AHP), developed by Saaty (1977, 1980), uses the same paradigm as MAVT, and is the source of several other variants, such as the geometric mean approach and various modifications to incorporate risk and multi-valued outcomes (Duke and Aull-Hyde 2002). The above MCDA approaches are regarded as being normative although the distinction between normative and positive in MCDA approaches is ambiguous.

Hajkowicz et al. (2000) classify MCDA methods as being either continuous or discrete (Janssen 1992). Discrete methods can be further subdivided into weighting methods and ranking methods (Nijkamp et al. 1990). Weighting and ranking methods can be further distinguished in terms of being qualitative/quantitative, mixed, or quantitative. Qualitative methods use only ordinal performance measures. Mixed qualitative and quantitative methods apply different decision rules based on the type of data that are encountered. Quantitative methods require the data to be measured in cardinal or ratio terms (Hajkowicz et al. 2000).

The practical significance of MCDA is that it improves the information basis of strategic planning, communication, and understanding in natural resource management. MCDA can be used in interactive decision making. The interaction becomes a dialogue where the model responds to an initial set of preferences and tradeoffs. The procedure progresses in an interactive manner until the decision maker has found a satisfactory solution. In this manner, MCDA provides a decision support system for policy makers.

MCDA has been widely used in environmental management (Bell 1975, Bakus et al. 1982, Janssen 1992), energy policy analysis (Haimes and Hall 1974, Keeney et al. 1995), farm management (Herath 1982, Xu et al. 1995, Prato et al. 1996a), food security (Haettenschwiler 1994), forest management (Kangas and Kuusipalo 1993, Kangas 1994, Penttinen 1994), protection of natural areas (Gehlbach 1975, Sargent and Brande 1976, Smith and Theberge 1986, Smith and Theberge 1987, Anselin et al. 1989), water management (Keeney et al. 1996), ecosystem management (Prato et al. 1996a, Prato 1999), soil and water management (Prato 1998) and wildlife management (Kangas et al. 1993, Prato et al. 1996b).

Purpose of this book

This book compiles several recent empirical applications of MCDA in natural resource planning, management, and policy analysis for both developing and developed countries. It explains and applies several MCDA approaches designed to assist readers in understanding the assumptions, strengths, and limitations of alternative approaches. The book establishes the context and practice of MCDA and is a source of reference for recent MCDA studies. It has an applications rather than theoretical orientation, and integrates standard techniques in a simplified framework.

There are twelve chapters. Chapter 1 sets the stage by discussing the origin and nature of natural resource management problems. It highlights limitations of traditional single-objective optimization models and advantages of MCDA techniques, and briefly summarizes each chapter.

Chapter 2 evaluates forest management options in the Northeast Victoria Regional Forest Agreement region in Australia using MAVT. Options are evaluated and ranked using aggregated preferences from single attribute value functions derived using the mid-value splitting technique. The option proposed by the government was not the most preferred one.

Chapter 3 evaluates several revegetation options to protect water courses in the Scheu Creek, a highly degraded small catchment in north Queensland, Australia, using the AHP. Differences in the rankings of revegetation options were due to differences in objectives of the various stakeholder groups. An optimal policy could not be identified.

Chapter 4 describes a multi-attribute method for prioritizing environmental and health risks associated with alternative management options for the Port Pirie lead and zinc smelter in south Australia.

Chapter 5 examines sustainable management alternatives for the Missouri River System in the USA. The MAE evaluation indicates that the preferred alternative selected by the US Army Corps of Engineers ranked above all six recommended alternatives based on four weight allocation schemes.

Chapter 6 is an empirical application of MCDA to integrated watershed management to improve water quality in the Goodwater Creek watershed in Missouri, USA. The MCDA model is used to select the best farming system from a finite set of alternative farming systems.

Chapter 7 evaluates the combined economic, environmental and social performance of ten Missouri farming systems for a representative 640- acre farm in north Central Missouri.

Chapter 8 is an application to the Canadian energy sector. Canada requires additional energy sources in the future and several alternative scenarios are being investigated. The alternatives are continuing to increase hydroelectricity, increase in natural gas, use of natural gas and cleaner coal, use 40 percent of base load from coal and hydroelectricity and use hydro and natural gas with improved natural gas turbines. MCDA is used to evaluate these five alternatives.

Chapter 9 is an application of AHP to sea port development in the Thi Vai – Cai Mep estuary in Vietnam. Four alternative sea port development scenarios were developed based on variations in government plans which were evaluated using AHP. The most preferred alternative was to retain the current level of development which has lowest environmental impacts.

Chapter 10 evaluates the potential of using the AHP to separately identify the use and non-use values of the Muthurajawela Marsh and the Negombo Lagoon (MMNL) area in Sri Lanka. AHP is also used to determine stakeholder preferences for conservation and development activities of wetlands.

Chapter 11 describes two potential applications of multiple attribute evaluation (MAE) to national park management. The first application explains how MAE is used to select a preferred management plan for a national park ecosystem, and the second application describes how to select a preferred management plan to bring a national park ecosystem into compliance with social and ecological carrying capacities.

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